*Euphytica* **100**: 1–5, 1998.

© 1998 *Kluwer Academic Publishers. Printed in the Netherlands.*

# Yield and stability factors associated with hybrid wheat

R. Bruns[1] & C. J. Peterson[2]
[1] *Agripro Seeds Inc., P.O. Box 30, Berthoud, CO, 80513, U.S.A.;* [2] *USDA-ARS University of Nebraska, Lincoln, NE, 68583, U.S.A.*

## Summary

For hybrid wheat to be accepted in the Great Plains of the USA, hybrids must exhibit enhanced yield performance, yield responsiveness, and reasonable yield stability across a wide array of production environments. Agripro has been researching hybrid wheat since 1981 and has an established pureline release history since 1978. Yield data from 1991 to 1995 were examined to compare the trend performance and selection gains of purelines and hybrids in a large scale parallel development effort. This data set (13,739 points) reveals an average 0.454 t ha$^{-1}$ or 10.8% hybrid yield advantage over purelines in preliminary regional testing. Entries selected from the preliminary trials show a greater hybrid advantage of 0.652 t ha$^{-1}$, or 13.5%. Several factors including enhanced stability over strong yearly environmental effects, improved agronomic and epidemiological expression through complementary inbred trait selection, and improved heat tolerance are likely contributors to this significantly improved selection gain. Yield stability of hybrids and purelines was compared in Agripro Standard Variety Trials and USDA-ARS Southern Regional Performance Nurseries from 1990 to 1995. In addition to having higher means than purelines, hybrid yield advantage increased with improving production conditions. The enhanced responsiveness of hybrids, as indicated by higher slopes in regression analyses, was combined with similar deviations from regression response. Hybrid wheat in the Great Plains of the USA has shown a fundamental yield, responsiveness and selection gain advantage over pureline varieties that could result in acceptance by producers.

## Introduction

Hybrid hard winter wheats (*Triticum aestivum* L.) have shown superior grain yield potential in regional and state performance trials over the last decade, but not at a level that would indicate an obvious economic benefit to growers. New information on hybrid yield potential and response to environmental variation is needed to demonstrate economic value and identify target production areas for hybrid wheat in the US Great Plains.

Carver et al. (1987) used Oklahoma performance trials to show that, although hybrids generally had higher mean yields, hybrid and semidwarf purelines cultivars had generally similar responses to production environments based on regression and cluster analyses. However, since the study by Carver et al. (1987), there have been significant advances in hybrid wheat breeding and seed production facilitated by development and use of experimental chemical hybridising agents (Mock, 1995). Compared with cytoplasmic male sterility systems, chemical hybridising agents provide means to generate large numbers of parental combinations, reduce time required for hybrid development, and improve hybrid breeding efficiency.

Agripro Seeds Inc. (ASI) has been in a unique situation to examine yield response of hybrid and pureline hard winter wheats. ASI has been breeding and releasing pureline varieties since 1974 and has had access to chemical hybridising agents since 1981. ASI has used its pureline breeding base to generate large numbers of hybrids that have been evaluated under parallel environments as the purelines. These factors allow us to examine a large standardised data set comparing grain yields and response to selection of purelines and hybrids.

A number of hybrids have been tested in the United States Department of Agriculture Agricultural Research Service (USADA-ARS) Southern Regional Performance Nursery (SRPN) over the last decade. The SRPN performance data have suggested that hybrids may have improved yield stability and response to favourable environments when grown over a broad array of production conditions. Analyses of multiple years of data and information from the SRPN and Agripro Standard Variety Trial (SVT), also grown region-wide, could more effectively establish differences in yield performance, yield stability, and responsiveness of hybrids and purelines, should differences exist.

## Materials and methods

Over time, ASI has developed a breeding strategy for purelines and hybrids that included parallel testing of preliminary purelines and preliminary hybrids at nearly the same scale, selection intensity, selection criteria, and yield testing scope. The breeding targets for purelines and hybrids have remained constant at 400-500 new entries of each in preliminary regional testing and 50-60 entries that advance to full scale regional evaluation. This balanced approach to hybrid and pureline testing enables a unique examination of a very large data set comparing purelines and hybrids derived from the same germplasm base.

Yield data of early generation hybrids and purelines were compared in Agripro preliminary yield trials grown from 1991-1994 and in advanced yield trials grown from 1992-1995. Yields for all entries were standardised by comparing performance to a standard control (Hawk) and include only locations where both purelines and hybrids were evaluated. Data from the preliminary trials consisted of 12,209 yield measurements (6010 pureline, 6199 hybrid) over 13 common location/years representing 3728 genotypes (1806 pureline, 1922 hybrid). In the following years of advanced trials, data consisted of 1530 yield values (796 pureline, 734 hybrid) over 13 common locations/years of tests representing 463 genotypes (246 pureline, 217 hybrid). Distributions of hybrid and pureline entry yields were contrasted in the preliminary and advanced trials. Differences in gain from selection were estimated by comparing mean yields of hybrids and purelines in the preliminary vs. selected hybrids and purelines in the advanced trials. Analyses were conducted by comparing the standard error of the differences of the mean of the populations.

Agripro utilises a proprietary computer software program that compares agronomic, pathologic, and quality traits of inbreds and provides a ranking of hybrid candidates prior to yield testing. This program effectively eliminates hybrids that have a critical flaw, and helps promote a higher percentage of hybrids that pyramid disease and pest protection genes. All hybrids tested are targeted to fall within acceptable agronomic, pathologic, and quality parameters.

Yield stability and environmental responsiveness of hybrids and purelines were compared using data from the Southern Regional Performance Nursery (SRPN), from 1990-1995, and Agripro Standard Variety Trial (SVT) in 1993 and 1994. Four to six hybrids were included in the SRPN trials and number of purelines included in analyses ranged from 30-36, as long term checks were excluded. The 1993 SVT included five Agripro hybrids and 20 purelines grown at nine locations in the Great Plains. The 1994 SVT included 16 Agripro hybrids and 28 purelines grown at 16 locations in the region. Each year of the SRPN and SVT were analysed separately as entries in the nurseries varied among years.

Pureline and hybrid yields were regressed on an environmental index based on average yield of pureline entries at each location, following the approach of Eberhart & Russell (1966). By doing so, average pureline regression slope was, by definition, $b = 1.0$, and average pureline intercept was at $0.0\ t\ ha^{-1}$. GLM (SAS Institute, 1982) was used to test heterogeneity of slopes between hybrids and purelines, and among entries within these two genotypic classes. Regression response of purelines and hybrids were plotted for each year and a 95% confidence interval was calculated to represent average variances around pureline and hybrid regressions.

*Table 1.* Summary of Agripro testing scope and mean yield deviation from control comparisons

| Preliminary trials | 1991 | 1992 | 1993 | 1994 | Totals |
|---|---|---|---|---|---|
| locations | 3 | 3 | 3 | 4 | 13 |
| pureline mean yield t ha$^{-1}$ | 0.223 | 0.551 | 1.127 | –0.380 | 0.333 |
| hybrid mean yield t ha$^{-1}$ | 0.526 | 1.198 | 1.465 | 0.036 | 0.787 |
| hybrid advantage t ha$^{-1}$ | 0.303** | 0.647** | 0.338** | 0.416** | 0.454** |
| % advantage | 10.0% | 14.0% | 7.4% | 9.6% | 10.8% |
| | | | | | |
| Advanced trials | 1992 | 1993 | 1994 | 1995 | Totals |
| locations | 3 | 3 | 2 | 5 | 13 |
| pureline mean yield t ha$^{-1}$ | 0.568 | 0.783 | –0.330 | 0.776 | 0.561 |
| hybrid mean yield t ha$^{-1}$ | 1.136 | 1.579 | –0.120 | 1.377 | 1.213 |
| hybrid advantage t ha$^{-1}$ | 0.568** | 0.796** | 0.210* | 0.601** | 0.652** |
| % advantage | 10.6% | 16.2% | 2.9% | 16.3% | 13.5% |
| pureline selection gain | 0.345** | 0.232** | –1.457** | 1.156** | 0.228** |
| hybrid selection gain | 0.610** | 0.381** | –1.590** | 1.341** | 0.426** |
| hybrid improved gain | 0.265* | 0.149 | –0.133 | 0.185** | 0.198** |

*, ** Significantly different from pureline values at the 0.05 and 0.01 probability levels, respectively.

## Results

Agripro breeding trials demonstrate a hybrid advantage of 0.454 t ha$^{-1}$ over purelines in preliminary yield trials, with an average yield level of 4.196 t ha$^{-1}$ (Table 1). This represents a 10.8% average hybrid advantage over four years of regional testing. The yield advantage of hybrids was significant in all four years as well as the four year pool. Details of testing scale and yield comparisons are illustrated in Table 1 and yield distributions are illustrated in Figure 1. Since the hybrid and pureline germplasm base are essentially the same, it can be assumed that the average heterosis level in this germplasm set would be approximately 10.8%.

When hybrid and pureline selections were tested in advanced trials, there was a hybrid advantage of 0.652 t ha$^{-1}$, at an average yield level of 4.835 t ha$^{-1}$. This represents a 13.5% average hybrid advantage over four years of regional testing. The yield advantage of hybrids was significant in all four years as well as the four year pool. Yield distributions are illustrated in Figure 2.

The 13.5% average hybrid advantage of advanced hybrids compared with 10.8% in the preliminary yield trials over a four year period demonstrates a significant gain-from-selection advantage for hybrids over purelines. Since the genetic base, selection intensity, and selection criteria for the purelines and the hybrids were essentially equal, this selection gain was unexpected.

The SRPN and SVT nurseries provided environments with a wide array of wheat production conditions, with location mean yields of purelines ranging from less than 1.0 to over 9.0 t ha$^{-1}$. In the SRPN, hybrid mean yields significantly exceeded the pure-

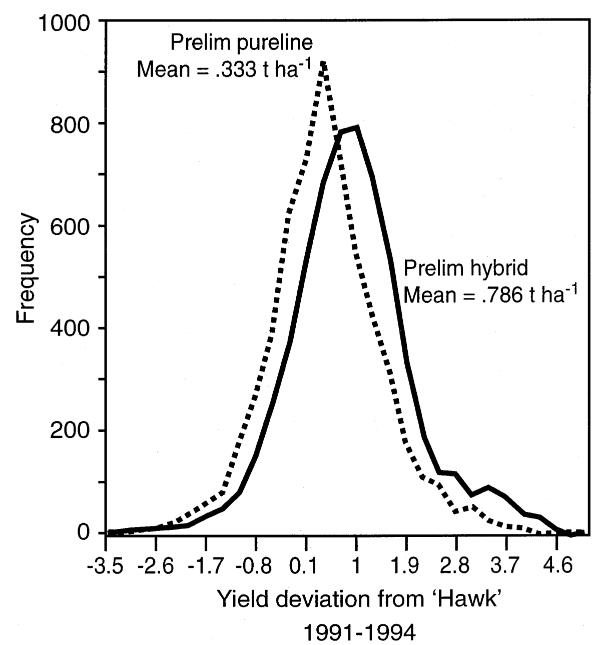


*Figure 1.* Four-year yield distributions: preliminary pureline vs. preliminary hybrid.

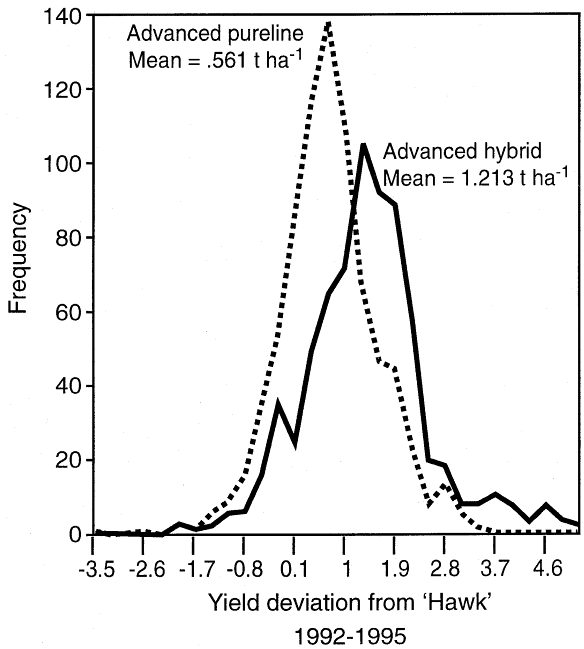


*Figure 2.* Four-year yield distributions: advanced pureline vs. advanced hybrid.

line means in all but one year, ranging from a 0.22 t $ha^{-1}$-0.46 t $ha^{-1}$ average yield advantage. In the 1993 and 1994 SVT, average hybrid yields exceeded the yield of pureline cultivars by 0.49 and 0.55 t $ha^{-1}$, respectively.

Regression response of both hybrid and pureline grain yields was linear in all years. There was significant heterogeneity for slopes among purelines in all but one of the trials. This heterogeneity was not unexpected, as the purelines evaluated in each nursery were of diverse genetic background and origin. Among hybrids tested, there was significant heterogeneity for regression slope only in the 1990 and 1991 SRPN, indicating that the hybrids had similar environmental responses each year.

Hybrids and purelines, as genotypic classes, showed significantly different responses to environmental variation in the SRPN in 1994 and 1995, and SVT in 1993 and 1994. In these trials, hybrid regression slopes ranged from b = 1.09 to 1.12 compared with b = 1.0 for purelines. However, average hybrid and pureline responses were not statistically different in the 1990-1993 SRPN trials. Pooled deviations from linear regression response, in terms of MS deviations and SE(b), were of similar magnitude for hybrids and purelines in each trial. As such, there was no evidence that hybrids provided an additional component of yield stability in terms of reduced

*Table 2.* Linear regression analyses of hybrid and pureline mean yields in the Southern Regional Performance Nursery (SRPN), 1990–1995, and Agripro Standard Variety Trial (SVT), 1993–1994

| | 1990 SRPN | 1991 SRPN | 1992 SRPN | 1993 SRPN |
|---|---|---|---|---|
| Hybrids | | | | |
| Mean, t $ha^{-1}$ | 3.54 | 3.67† | 3.85* | 4.78** |
| Intercept | 0.00 | 0.10 | 0.02 | 0.43 |
| b | 1.06 | 1.04 | 1.07 | 1.00 |
| SE(b) | 0.05 | 0.04 | 0.02 | 0.05 |
| Purelines‡ | | | | |
| Mean, t $ha^{-1}$ | 3.34 | 3.45 | 3.58 | 4.38 |
| SE(b) | 0.06 | 0.05 | 0.06 | 0.06 |
| | 1994 SRPN | 1995 SRPN | 1993 SVT | 1994 SVT |
| Hybrids | | | | |
| Mean, t $ha^{-1}$ | 3.64** | 3.47** | 4.81** | 4.70** |
| Intercept | 0.17 | 0.04 | 0.12 | 0.00 |
| b | 1.09* | 1.10† | 1.10* | 1.12** |
| SE(b) | 0.07 | 0.08 | 0.05 | 0.06 |
| Purelines‡ | | | | |
| Mean, t $ha^{-1}$ | 3.18 | 3.13 | 4.25 | 4.21 |
| SE(b) | 0.07 | 0.07 | 0.06 | 0.05 |

†, *, ** Significantly different from pureline values at the 0.10, 0.05, and 0.01 probability levels, respectively.

‡ Intercept and b values for average pureline response are 0.0 and 1.0, respectively, for each trial.

deviations from expected response. However, there was also no associated increase in deviations, as might have occurred considering the enhanced responsiveness and higher mean yields in the hybrids. Detailed regression analyses of hybrid and pureline mean yield response for the SRPN and SVT is illustrated in Table 2.

There was no crossover between hybrid and pureline regression responses indicated in any of the trials. In the SRPN trials, the 95% CI for hybrid and pureline yield responses mostly overlapped. In the 1993 and 1994 SVT, hybrid and pureline confidence intervals overlapped at lower yield levels, but as environmental yield potential exceeded approximately 3.5 t $ha^{-1}$, the hybrid and pureline confidence intervals diverge. This would suggest a high probability for hybrid yields to exceed pureline yields in these more favourable environments.

## Discussion and conclusion

Multiple year performance trial data comparing purelines and hybrids at both preliminary and advanced stages show strong evidence for substantial hybrid yield advantage, hybrid responsiveness to favourable environments, and similar deviations from regression response. There is a significant improvement of selection efficiency of the hybrid group relative to purelines. The improved selection gain must be attributed to one or a combination of the following factors:

1. Enhanced stability over strong yearly environmental effects is plausible, but has to be tempered by the fact that within year stability deviation from response is essentially equal among hybrids and purelines.
2. Improved agronomic and epidemiological expression through computer assisted complementary inbred trait selection.
3. Heterosis for green leaf duration that is manifested by improved heat tolerance. (Van Meeteren, 1995).

Understanding the components of this improved selection gain in Great Plains hybrids through targeted experiments is warranted.

With continued development and appropriate hybrid selection strategies, hybrids can provide growers with added value expressed through a high probability of enhanced grain yield and improved yield responsiveness, combined with similar levels of yield stability relative to conventional pureline cultivars. If this added value is greater than hybrid seed production expense, hybrids may be accepted on a wide scale in the Great Plains of the USA.

## References

Carver, B.F., E.L. Smith & H.O. England, Jr., 1987. Regression and cluster analysis of environmental responses of hybrid and pureline winter wheat cultivars. Crop Sci 27: 659-664.

Eberhart, S.A. & W.A. Russell, 1966. Stability parameters for comparing varieties. Agronomy J 6: 36-40.

Mock, J.J., 1995. A new look at hybrid wheat and its role in improving yield and quality. In: C.J. Peterson (Ed.), Proceedings of the North American Wheat Workers Workshop, 1994, pp. 20-34. National Wheat Improvement Committee. Kansas City.

SAS Institute, 1982. SAS user's guide: Statistics. SAS Institute Inc., Cary, NC.

Van Meeteren, N.D, 1995. Hybrid and pureline response to high temperature stress at two growth stages in hard red winter wheat. Agronomy Abstracts 87: 80.